Radiation Physics Note 63

Conversion Factors Relating Particle Fluence (Flux) and Dose Equivalent: An Update

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1. Hadrons

Factors for the conversion of hadron fluence to dose equivalent for high-energy beams were calculated by Armstrong and Chandler in 1972 (Ar 73). These were based on an infinitely broad beam of monoenergetic neutrons or protons incident on one side of a semi-infinite slab of tissue 30 cm thick. Gollon (Go 76) summarized these measurements for protons up to 200 GeV. More recently, Stevenson (St 86) presented the results of a review of high-energy data and calculations (up to 1 TeV) by an ICRP task group. A summary of these latter results are presented here to update and extend Gollon's memo.

In Fig. 1, factors, from Stevenson's paper (St 86), to convert particle fluence to hadron dose equivalent are plotted as a function of energy. Hadron flux (fluence rate) to dose equivalent rate factors are presented in Fig. 2 as an added convenience in some applications. The values for pions are averages for negatively and positively charged particles.

The dose equivalent discussed by Stevenson is the so-called ambient dose equivalent (IC 85). It is defined as the value at a depth of 1 cm in a 30 cm diameter tissue-equivalent sphere, and is recommended by the ICRU (IC 85) as the operational quantity for radiation protection since it is a more rigorous way of defining the dose equivalent at the surface of a body. It is generally the value determined by a tissue-equivalent ion chamber, but it is <u>not</u> the maximum dose equivalent developed in a 30 cm thick tissue-equivalent phantom placed directly in an hadron beam.

Conversion of fluence to dose equivalent outside of the earth and concrete shield of an high-energy accelerator depends on the type and spectrum of particles that leak through the shield. Stevenson (St 84) has shown that the conversion factor, 0.1 mrem-hr⁻¹ per unit flux of one particle cm⁻²-sec⁻¹ (28 fSv-m²), long in use at CERN, agrees with calculations for a pure neutron leakage spectrum (e.g., outside of lateral shielding), while a value of 0.16 mrem-hr⁻¹ per unit flux (45 fSv-m²) is better for leakage spectra that contain a charged particle component (protons, pions) (as e.g., in the forward direction relative to the accelerator beam). It is noted that outside of shielding (in contrast to "in the direct beam") the maximum of the depth dose equivalent distribution will lie close to the body surface (Th 85) and so is what is determined by use of a tissue-equivalent ion chamber.

2. Muons

Conversion factors for muons are related to the rate of energy loss (or stopping power) dE/dx in matter (PD 86) by (1.603 x 10⁻⁵) x (dE/dx) in units of mrem per muon-cm⁻², when dE/dx is in MeV-cm²-g⁻¹, and all contributions to the dose have unit quality factor. Stevenson (St 83) has discussed and summarized the present knowledge of dose and dose equivalent for muons with energies up to 1 TeV.

At high energies muons lose energy by bremsstrahlung, direct pair production, and nuclear inelastic interactions as well as by ionization and excitation in atomic collisions. Stevenson (St 83) has pointed out that since energy lost by bremsstrahlung is not absorbed locally only the contributions from other loss mechanisms contribute to muon absorbed dose. The dose equivalent per unit fluence in tissue obtained from Stevenson's calculated energy-loss is shown as the solid line in Fig. 3, and compared to results for total energy loss (including bremsstrahlung) and the loss due to ionization and excitation only. Muon flux-to-dose equivalent rates are shown in Fig. 4 for the same loss mechanisms.

As seen in the figures other energy-loss mechanisms than ionization and excitation in atomic collisions start to contribute significantly at muon energies near 100 GeV. To within about 20% a unique conversion factor (St 83) of 4 x 10⁻⁵ mrem per unit fluence (25000 muons-cm⁻² per mrem) represents a good approximation for muons with energies between 0.1 and 100 GeV.

Koizumi (Ko 78) has also calculated muon energy loss for energies up to 1 TeV. However no results for tissue nor any tissue element have been tabulated. Results were however presented for "moist" soil (10% water), and conversion factors based on these are shown in Fig. 5 compared to the results for tissue from the compilation of Stevenson (St 83). Differences in the shapes of these curves may point to some difficulties with energy-loss calculations at high muon energies.

⁺Hydrogen-10%; Carbon-11%; Nitrogen-2.6%; Oxygen-76.2%

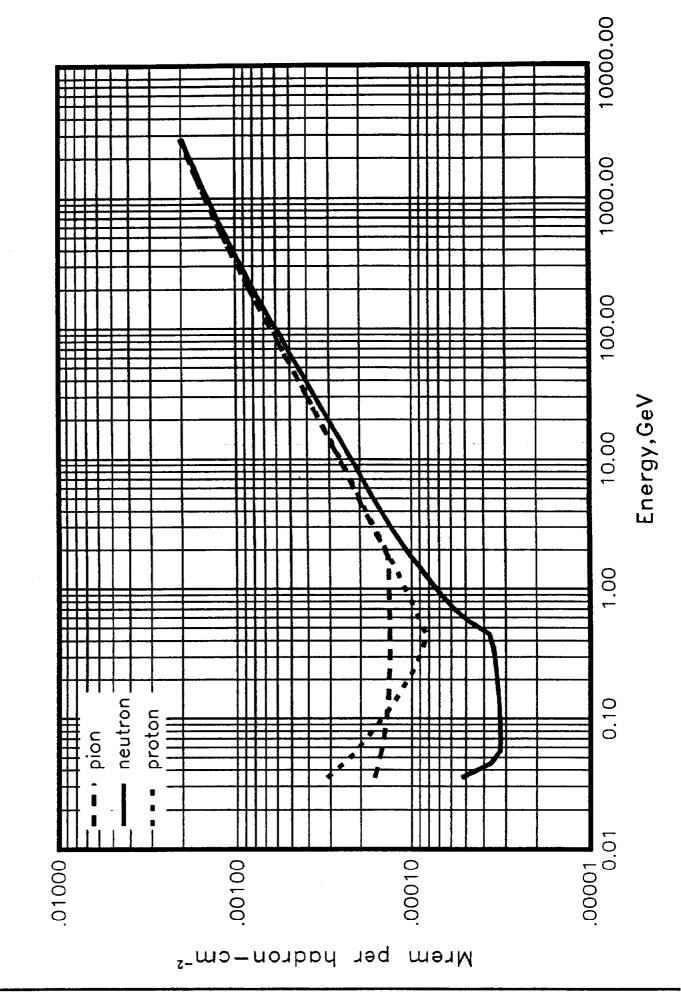
References

- (Ar 73) T. W. Armstrong and K. C. Chandler, "Calculation of the Absorbed Dose and Dose Equivalent from Neutrons and Protons in the Energy Range from 3.5 GeV to 1.0 TeV," Health Phys. 24, 277 (1973)
- (Go 76) Peter Gollon, <u>Doses from Hadron Beams</u>, Rad. Phys. Note 14, 1976, Fermi National Accelerator Laboratory, Batavia, IL, 60510
- (Ko 78) G. Koizumi, Muon dE/dx and Range Tables for Tevatron Energies: Results for Some Shielding Materials, TM-786, 1978, Fermi National Accelerator Laboratory, Batavia, IL, 60510
- (IC 85) Determination of Dose Equivalents Resulting from External Sources, ICRU Report 39, 1985, Int. Comm. on Rad. Units and Measurements, Bethesda, MD, 20814
- (PD 86) See, for example, Particle Data Group, "Review of Particle Properties," Phys. Letters 170B, 1 (1986).
- (St 83) G. R. Stevenson, <u>Dose and Dose Equivalent from Muons</u>, Report TIS-RP/099, 1983, CERN, Geneva, Switzerland
- (St 84) G. R. Stevenson, "The Estimation of Dose Equivalent from the Activation of Plastic Scintillator," Health Phys. 47, 837 (1984)
- (St 86) G. R. Stevenson, <u>Dose Equivalent per Star in Hadron Cascades</u>, Report TIS-RP/173, 1986, CERN, Geneva, Switzerland

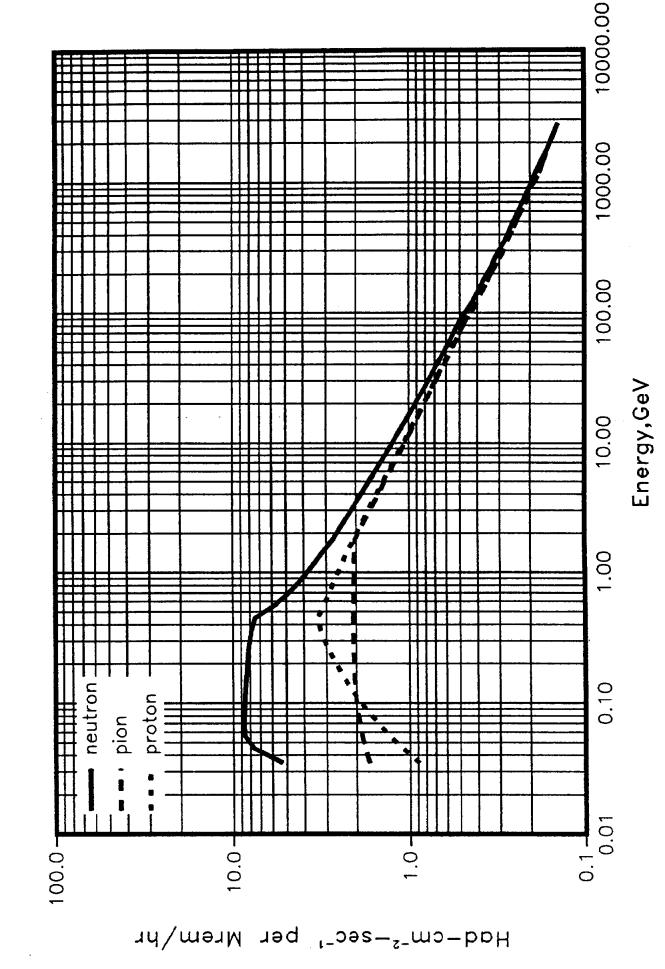
Figures

- 1. Hadron dose equivalent per unit fluence as a function of hadron energy. Pion results are averages for negatively and positively charged particles.
- 2. Hadron flux per mrem/hr as a function of hadron energy.
- 3. Muon dose equivalent per unit fluence as a function of energy based on muon dE/dx values for the sum of all loss mechanisms (Tot), all losses except bremsstrahlung (Tot-Brem), and losses due to atomic ionization only (Ion).
- 4. Muon flux per mrem/hr as a function of energy, based on muon dE/dx values as discussed in the caption for Fig. 3.
- 5. Muon dose equivalent per unit fluence as a function of energy based on dE/dx values for the sum of all loss contributions for "moist" soil from (Ko 78) and tissue from (St 83).

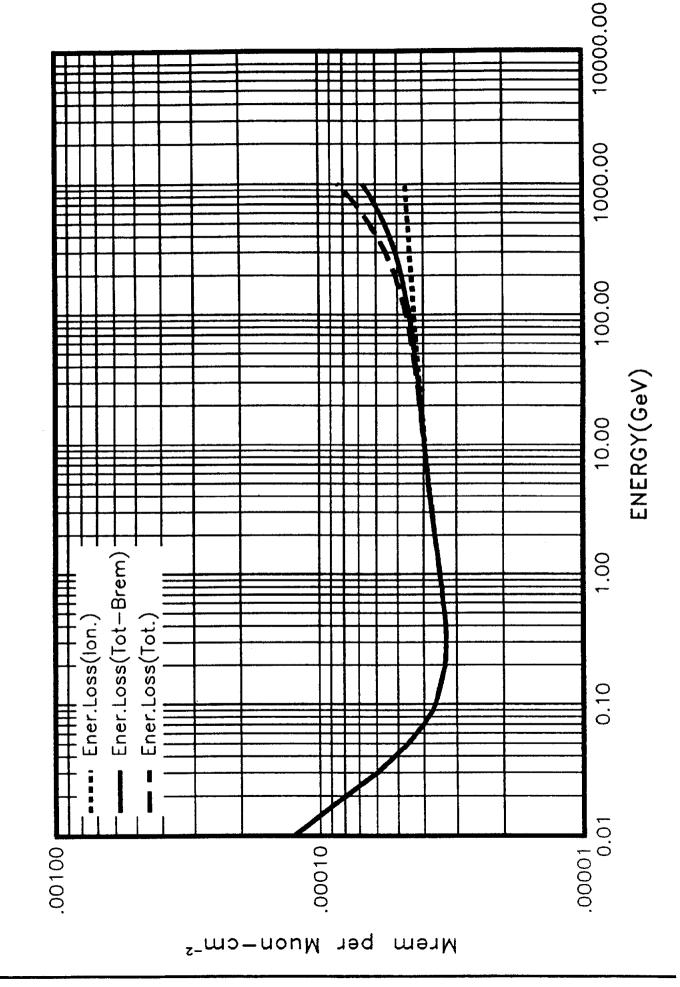
HADRON DOSE EQUIVALENT-FLUENCE CONVERSION FACTOR



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